Simulation of calculation of combat vehicle fuel efficiency by reducing vehicle weight using aluminum material

Jofim Yordaniel N*
Republic of Indonesia Defense University,
INDONESIA

Riri Murniati
Republic of Indonesia Defense University,
INDONESIA

Adhi Kusumadjati
Republic of Indonesia Defense University,
INDONESIA

Agung Hirawan
Republic of Indonesia Defense University,
INDONESIA

Mochamad Ibnu Alwan
Republic of Indonesia Defense University,
INDONESIA

Ramandasoavina Blanchard
University of Antananarivo
MADAGASCAR

Article Info	Abstract
	In the contemporary landscape, combat vehicles are tasked with meeting multifaceted demands, ranging from fortified defense capabilities to enhanced operational versatility and lethal efficacy. At the crux of these requirements lies the pivotal challenge of managing vehicular weight, a parameter that profoundly impacts endurance, agility, and speed. Extensive research endeavors have shed light on aluminum as a compelling solution to mitigate this weight burden while ensuring the requisite durability in combat vehicles. Through the utilization of MATLAB simulations, this study endeavors to elucidate the correlation between mass reduction and fuel efficiency, culminating in the creation of a comparative graph. The findings of this research make a significant contribution by demonstrating that a 15% reduction in vehicle mass, equivalent to 324 kilograms through the substitution of conventional materials with aluminum, yields substantial fuel savings amounting to 13.36%, or 1.3 liters. Such insights underscore the pivotal role of material selection in optimizing fuel efficiency in combat vehicle design

INTRODUCTION

A strong defense along with a wide and fast expedition to conduct special operations is currently very important for the Army. Despite the advantages of lightweight vehicles, the challenge is the weight of the vehicle. The lighter weight of the vehicle will usually decrease its power performance. Lightweight vehicles deserve a lot of attention as significant energy savings are necessary for the economic sustainability of a country today and in the future. The Army's ground vehicles are getting heavier as threat mitigation technologies are introduced, so changing the mass of the vehicle is important to get the best performance. Future emissions regulations and fuel efficiency standards for vehicle engines are expected to become increasingly stringent, with a particular focus on engine design and aftercare technology (Beatrice et al., 2016).

New techniques are needed for more accurate vehicle energy that aims to reduce energy consumption atau each that aims to reduce rider anxiety when long range is required (Miri et al., 2021). The technical efficiency of vehicles has been increasing slowly, with recent years showing only a half offset of the global figure (Lovins, 2020). Hence, there is a necessity for ongoing research

*Corresponding Author:
Jofim Yordaniel N, Republic of Indonesia Defense University, Indonesia, Email: jofimyn70@gmail.com

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focused on enhancing vehicle efficiency. There is significant potential to reduce the weight of the vehicle fleet by examining both manufacturing and usage perspectives, particularly by implementing lightweight vehicle designs (Das et al., 2016).
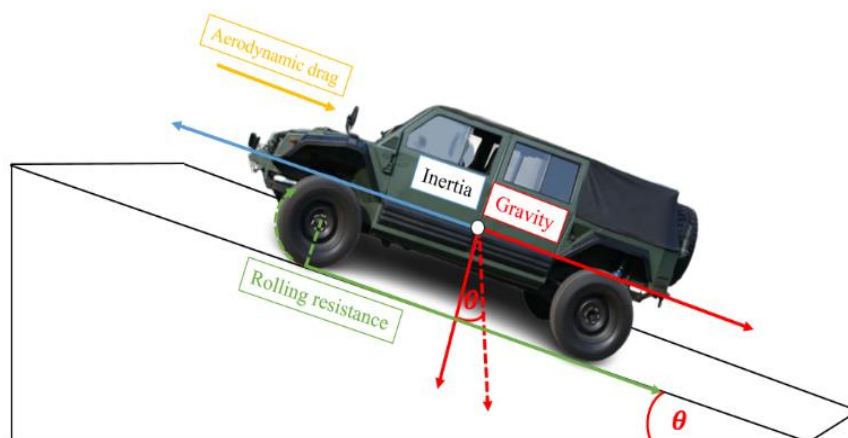
A 10% diminish in vehicle weight can lead to a 6%–8% enhancement in fuel proficiency (Joost, 2012). Vehicle body weight can be reduced to the maximum by replacing conventional press engine components and vehicle body materials with lightweight aluminum components (Zhang & Xu, 2022; Chappuis & Sanders, 2019). This study will show the simulation of mass reduction calculations on vehicles that will improve fuel efficiency by using aluminum material. The vehicle that will be simulated is the Maung Tactical Vehicle which is made by PT Pindad with a vehicle mass of 2,160 kg, which is mostly made of steel (PT. Pindad (Persero), 2024). The reason for simulating the mass of the vehicle is that the load of this military vehicle has a heavy load of equipment and troops.

In recent years, there has been a growing demand for steel in high-stress structures, particularly in critical applications in defense such as constructing combat vehicle hulls and turrets (Magudeeswaran et al., 2018). To address this, there is a need for alternative materials that offer equivalent or superior advantages to steel while being lighter in weight. The materials commonly utilized in automotive engineering include high- and ultra-high-strength steel, aluminum, magnesium, and fiber-reinforced plastics. Aluminum, in particular, is a lightweight metal with a density of only 2.7 g/cm^3. (Afseth, 2017).

The selection of aluminum material is predicated upon its inherent properties, which serve as fundamental considerations in vehicular engineering. Aluminum's corrosion resistance and lightweight nature imbue vehicles with accelerated performance characteristics, attributed to its ability to mitigate rust formation and reduce overall mass (Maharnwar, 2016). Ultra-high-strength aluminum alloys have the potential to challenge steel's dominant position in vehicle components requiring limited strength. These intrinsic attributes underscore aluminum's efficacy as a preferred material choice, aligning with the imperative of enhancing vehicular dynamics and operational efficiency (Energy.Gov, 2024). The quality of aluminum directly impacts both the strength of the vehicle body and the quality of assembly. This quality primarily encompasses strength indexes and shape precision (Hao et al., 2010).

METHOD

The energy formulation governing vehicle fuel consumption necessitates a comprehensive examination of various force components acting upon the vehicle (see Figure 1). Through meticulous analysis, a scalar representation of the resultant force is derived, facilitating the computation of the total load power requisite for vehicular propulsion. This multifaceted approach encapsulates the intricate interplay between mechanical forces and energy dynamics, crucial for elucidating the intricate mechanisms underlying vehicular motion and fuel utilization (Zacharof et al., 2024).

Figure 1. The forces involved in the movement of the Tactical Maung

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The calculation that describes the vehicle situation above is the Power Equation which applies Basic Physics Equations. It is necessary to develop a fast and light vehicle dynamics model that is oriented towards vehicle electrification so that any efficiency calculations are not overlooked (Soldati et al., 2019).

$$P_{load} = P_{Rolling} + P_{Drag} + P_{Inertial} + P_{Climb} \qquad (1)$$

The depicted equation serves as a comprehensive depiction of the dynamic forces exerted upon the combat vehicle during operation. P_{load}, signifying the aggregate power demand requisite for vehicular propulsion, encapsulates the cumulative effects of $P_{Rolling}$, P_{Drag}, $P_{Inertia}$, and P_{Climb}. It is imperative to note that power, measured in Joules per second (J/s) or Watts (W), serves as a fundamental metric for quantifying the energy expenditure inherent in vehicular motion. Where the explanation of each power load on the vehicle is explained below.

As we know that a car or vehicle moves with the rotational force of the wheels. Rotation, namely on vehicle tires that run directly with uneven road layers will result in a drag force that accelerates rotation.

$$P_{Rolling} = C_R M_t g v_s \qquad (2)$$

C_R is the coefficient of rotational drag, M_t is the vehicle's overall mass (kg), g is the value of the gravitational acceleration ($9.81\ m/s^2$), v_s is the vehicle speed (m/s). From the above formula, it can be seen that the mass constant of the vehicle greatly affects the value of the power load on the vehicle. So, if we regulate or manage the mass by reducing it, it will result in a decrease in the required power load which results in reduced fuel requirements.

In the movement of vehicles, it is undeniable that air resistance will hinder the movement of the vehicle. Therefore, it takes the best design for the vehicle from the front to the rear so that it is an aerodynamic shape. For the movement of the vehicle to be good, the vehicle area is made to a minimum or made aerodynamic (Abo-Serie, 2017).

$$P_{Drag} = \frac{\frac{1}{2}\rho_{air} C_D A v_s^3}{1000} \qquad (3)$$

ρ_{air} is the air's density (kg/m^3), C_D is the air resistance coefficient's value, and A's value represents the vehicle's front surface area (m^2)

As is known, all objects have the property to maintain their position, so that if we have the position or position of the vehicle moving with a certain acceleration, we will get the value of the object's work. We can say that this power is the effort to run the vehicle.

$$P_{inertial} = \frac{1}{2} M_t (a.v_s) \qquad (4)$$

From the above formula, it is clear that the mass constant of the vehicle is seen to greatly affect the value of the power load on the vehicle, a is the acceleration value of the vehicle (km/h^2). So if we regulate or manage the mass by being reduced or reduced it will result in the required Power Load will decrease which results in reduced fuel requirements.

We cannot deny that the strength of the gravitational field or the acceleration of gravity will affect every object or object. Likewise with this vehicle, when an object is uphill on a high road, a force is needed to shift the position of the object or object. If we see an object moving up then the acceleration of gravity will hinder the movement of the vehicle with mass as the main factor.

$$P_{climb} = M_t g \sin\theta . v_S \qquad (5)$$

From the above formula, θ shows the slope of the incline traversed by the vehicle from the above formula, it can be seen that the mass constant of the vehicle greatly affects the value of the

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power load on the vehicle. So, if we adjust or adjust the mass by reducing or reducing it will result in the required Power Load will be reduced.

Equation (1) is the sum of the power in each force acting on the vehicle. To obtain a formulation of the total power required from the simulation, add equations (2), (3), (4) and (5) into equation (1). Then we will get the total load needed:

$$P_{load} = \frac{\frac{1}{2}\rho C_D A v^3}{1000} + M_t \left(C_R g v_s + \frac{1}{2}[a.v_s] + g v_s \sin\theta \right) \tag{6}$$

The formula for the value of the fuel needed uses the equation below.

$$Q = \frac{P_{load}}{H . \eta} \tag{7}$$

Q is the value of liters of fuel per unit hour, H is the value of the form of calorific value (kWh/l), and η is the efficiency of the combustion engine.

In this calculation, we assume that the tactical combat vehicle is traveling at an initial speed of 70 km/h with a track distance of 95 km accompanied by an incline angle of 0 and 10 degrees. In the simulation, the Maung Taktis combat vehicle is subjected to travel parameters consisting of an initial speed of 70 km/h, a final speed of 120 km/h, and an acceleration of 50 km/h within a duration of 1 hour. Data regarding the value of constants for the calculation of the resultant force we are looking for from several sources. The simulation was designed to replicate the vehicle's trajectory on terrain characterized by slopes ranging from 0 to 10 degrees, with a total track length of 95 kilometers. The following table contains the parameter values used for the calculation.

**Table 1.** Parameter values used in calculations

No	Symbol	Value
1	C_R	0.015
2	M_t	2160 kg
3	v_s	70 km/h
4	C_D	0.64
5	θ	0° , 10°
6	H	9.9 kWh/l
7	η	95 %
8	a	50 km/h^2
9	ρ_{air}	1.2 kg/m^3
10	g	9.81 m/s^2
11	A	2.99 m^2

In this investigation, a methodological approach rooted in simplicity is employed for computational analysis, utilizing MATLAB software. Initial delineation of the research problem focuses on elucidating the pronounced inefficiencies associated with the utilization of heavy materials in transportation systems. Subsequently, a theoretical framework is established through the application of fundamental principles, notably Newton's Second Law of Motion, wherein an equation is derived to encapsulate the theoretical underpinnings of the study. This equation serves as a cornerstone within the computational framework. The ensuing step involves the procurement and collation of pertinent data, sourced from a myriad of reputable references, as exemplified in Table 1, herein referred to as the Parameter Table. Finally, a comprehensive examination and discussion of the computed results derived from the input data ensue, thereby providing insights into the intricacies of the research problem under consideration.

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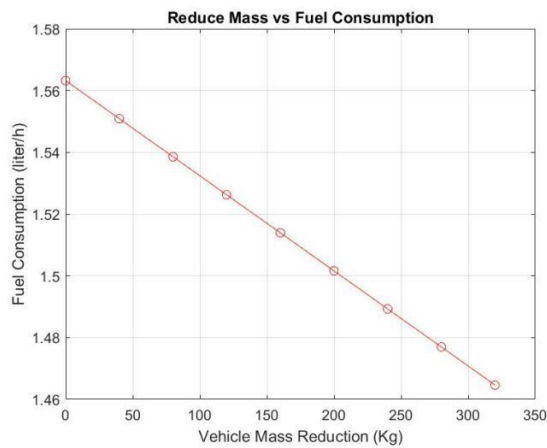
RESULTS AND DISCUSSION

In the empirical investigation concerning the correlation between mass diminution and fuel consumption, the utilization of the MATLAB computational tool was imperative. Through meticulous computation facilitated by MATLAB, empirical evidence elucidates the profound efficacy of employing aluminum composite materials in effectuating a reduction in vehicular mass by 324 kilograms. Understanding fundamental thermodynamics and kinetics becomes crucial when calculating the suitability of materials for computationally designing alloys(Sudbrack & Hardy, 2014). Illustrated graphically, the findings underscore a direct relationship between the magnitude of mass reduction and the consequential decrease in fuel consumption. Notably, the analytical procedures were conducted on combat vehicles, specifically the Maung Tactical vehicles manufactured by PT. PINDAD, wherein substantial reductions in fuel consumption were observed commensurate with mass diminution within the range of 0% to 15%. It is noteworthy that the initial mass of the vehicle stood at approximately 2160 kilograms, thus rendering the achieved mass reduction of 15% via aluminum substitution equivalent to 324 kilograms.

The research findings indicate that vehicle efficiency values, particularly fuel efficiency, are influenced by several factors. Consequently, increasing efficiency is not a straightforward task in theory. The fuel energy consumption of a vehicle depends on two main factors: (1) the workload or power required to move the vehicle and operate its accessories, which is influenced by the vehicle load, and (2) the energy efficiency of the powertrain, comprising the engine and transmission (Ross, 1997).

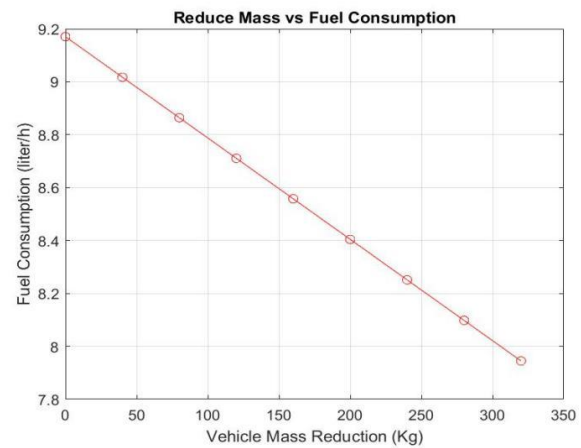(a) 0°   (b) 10°
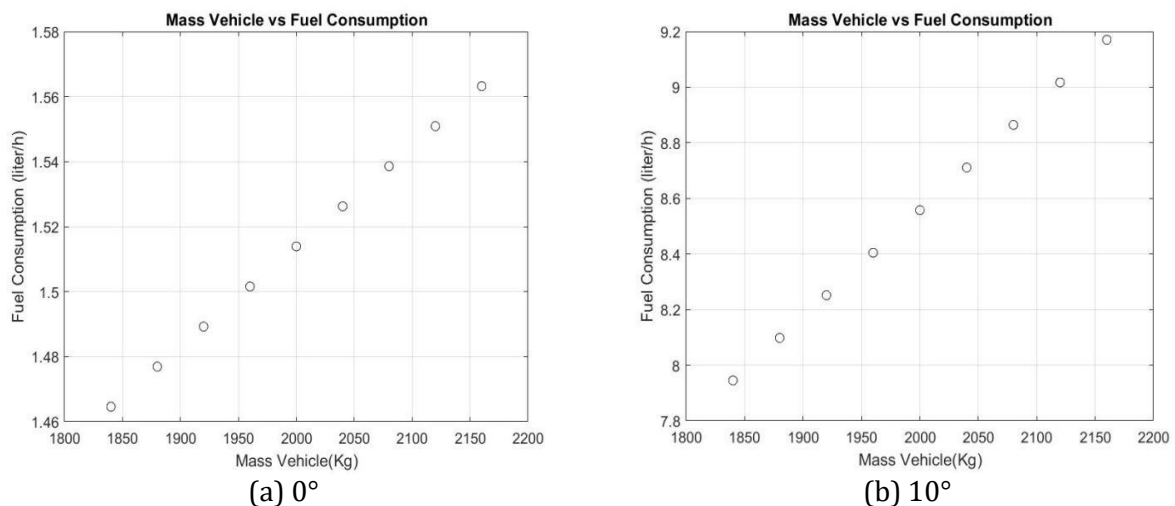
Figure 2. The appearance of the value of the increase in fuel demand when the mass is increased. images that are (a) for values of 0 degrees or no incline angle and images that are (b) for 10 degrees on incline.

From the Computational Results it is clear that mass serves as an important determinant in the calculation of the power load exerted on the vehicle. Through theoretical analysis based on the basic principles of mechanics, it is evident that the reduction in vehicle mass is inversely correlated with the magnitude of the power load, thus triggering a commensurate reduction in fuel requirements. This explains the fundamental relationship between mass reduction and fuel efficiency, underlying the importance of mass optimization strategies in the field of vehicle engineering. Figures 2, 3, and 4 delineate a discernible correlation: as the mass of the vehicle escalates, a proportional augmentation in required load power becomes evident, conversely, a decrease in load power requisite is observed with an increase in vehicular mass. Noteworthy in Table 1, which aggregates data meticulously curated from diverse sources, are values indicative of the magnitude of mass reduction, thereby facilitating straightforward calculations to elucidate the efficacy of mass diminution strategies.

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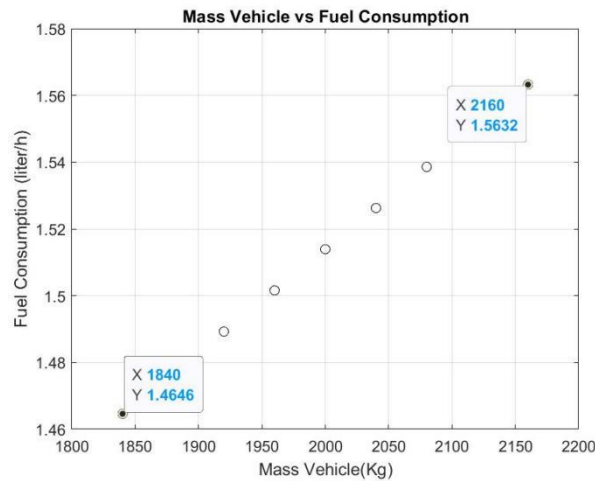
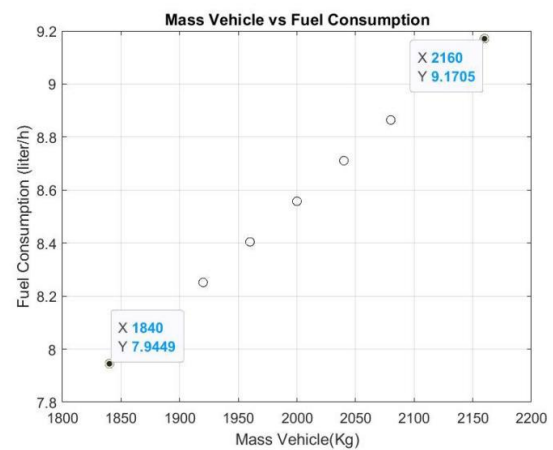(a) 0°   (b) 10°

Figure 3. The appearance of reduced mass results in reduced fuel consumption. Images that are (a) for values of 0 degrees or no incline angle and images that are (b) for 10 degrees on incline.

(a) 0°   (b) 10°

Figure 4. Relationship of mass reduction in Maung Tactical vehicles. Mass Reduction Comparison 0% to 15%. (a) for values of 0 degrees or no incline angle and images that are (b) for 10 degrees on incline.

As depicted in Figure 2(a), at a slope of 0 degrees, maintaining the Tactical Maung's mass at 2160 kg yields a fuel consumption of 1.5632 liters. Conversely, implementing a 15% mass reduction reduces fuel consumption to 1.4646 liters. This corresponds to a savings of 0.0986 liters, or approximately 0.1 liter, over a 1-hour journey in a diesel vehicle covering a distance of 95 km. A diesel engine is a type of internal combustion engine that generates mechanical work by burning fuel to release energy from its chemical bonds through combustion(Fiebig et al., 2014). The recorded reduction in fuel consumption, achieved through a 324 kg mass reduction with aluminum substitution, underscores the efficacy of this strategy. Furthermore, the calculated 6.3% improvement in fuel economy substantiates a noteworthy reduction in fuel consumption, affirming the significance of mass optimization measures in vehicular design. Reducing the critical mass will also decrease the overall size of the vehicle, consequently altering the vehicle's aerodynamic shape and enhancing its speed (Polsen et al., 2014).

As depicted in Figure 2(b) that is 10 degrees, a mass reduction of 0% on the Tactical Maung with a mass of 2160 kg will result in a fuel requirement of 9.1705 liters, and a mass reduction of 15% on the vehicle will result in a fuel requirement of 7.9449 liters. The achievement attained 1.2256 L or saves 1.2 liter of gasoline for a 1-hour travel in a diesel vehicle or a 1-hour drive over a 95 km distance with the recording of fuel to lower the mass of 324 kg with aluminum. With a 15% reduction,

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this calculation shows that the fuel economy is 13.36%, which is a significant decrease in fuel consumption.

Despite not moving, the engine still uses fuel, therefore material use is still reasonable. All tested technologies used the same methodology. In fact, a moving vehicle will definitely go through inclines and descents, so that the calculation of specific fuel additions will be very difficult. In this calculation we do it in general, namely by taking a view when the car passes an incline angle of 0 degrees or on a straight road and an incline angle of 10 degrees or uphill on a plateau.

This mass reduction will help accelerate the shift to alternative fuels and powertrain electrification as well as improve the efficiency of conventional vehicles (Haraguchi, 2011). By comparing the results of this study with previous research which states that a mass reduction of 10% results in fuel savings of 6%-8% (Joost, 2012), from these values it is found that there is a significant difference in this simulation by stating that a mass reduction of up to 15% obtained fuel savings of up to 13.36%. This study shows that a true mass reduction of 10%-15% with aluminum replacement can increase fuel efficiency up to 6%-13.36%. This can happen because there are several influencing factors. First, reliance solely on data acquisition from various sources, without direct experimentation, is a substantive limitation. Secondly, the omission to measure the resistance exerted on the vehicle components and the additional forces encountered during vehicle idling further exacerbates the limitations of this study. A good engine is one that consistently motivates advancements in efficiency and performance, exemplified by the evolution of direct gasoline injection engines(Wong & Tung, 2016). Thirdly, not accounting for the consumption of electric power by auxiliary systems in the vehicle, which include lighting, electronic peripherals, and climate control mechanisms, is an additional shortcoming. The production of lighter vehicles leads to lower fuel consumption during vehicle usage compared to the base vehicle (Peppas et al., 2021).

Despite these limitations, this study reveals important insights into the substantial impact of vehicle mass on fuel requirements. It is imperative to recognize that combat vehicles, which operate in dynamic environments characterized by poor topography, require an optimal mass distribution to maintain operational efficacy without compromising fuel economy (Day, 2018). If the mass of the vehicle body is decreased by using materials with lower density, it enables the integration of smaller, lighter, and potentially more efficient powertrains, which can enhance acceleration performance (Caffrey et al., 2015).

CONCLUSION

Through meticulous calculations, it was determined that a reduction in vehicle mass of 324 kilograms through the adoption of aluminum material yields significant fuel savings. On a 95-kilometer track with a slope of 0 degrees, the calculated fuel savings amount to approximately 0.0986 liters per hour, whereas on a slope of 10 degrees, the savings escalate to approximately 1.2256 liters per hour. These findings translate to a commendable fuel saving of 6.3% and 13.36%, respectively, corresponding to the 15% mass reduction. Such outcomes underscore the tangible benefits of mass reduction strategies in augmenting fuel efficiency, especially when navigating challenging terrains. It is evident that optimizing vehicle mass is imperative for ensuring optimal performance without compromising operational functionality, particularly in scenarios characterized by adverse topographies and varying inclines.

Mass reduction holds paramount significance for military vehicles, as it engenders substantial fuel economy, thereby manifesting as a prudent fiscal measure beneficial to the state budget. The adoption of lightweight and durable materials, exemplified by aluminum, not only garners significant fuel efficiencies but also augments vehicular agility and velocity. This symbiotic relationship between mass reduction and material optimization underscores a strategic imperative in enhancing military vehicle performance while optimizing resource allocation.

AUTHOR CONTRIBUTIONS

Each author of this article played an important role in the process of method conceptualization, simulation, and article writing.

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